Noise at the Crossover from Wigner Liquid to Wigner Glass

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Three-dimensional metals have long been known to exist, but when two-dimensional (2-D) electronic systems were first studied in the early 1980s, it was believed on theoretical grounds that a 2-D metallic state could never occur. As the quality of the experimental samples improved over the following decade, more and more evidence emerged of a transition from insulating to metallic behavior for systems in which the electron density exceeds some sample-dependent critical value. Single-electron theories were developed to explain the transition, but these theories were unable to capture the noise behavior observed in recent experiments.

To address the microscopic mechanism of the 2-D metal-insulator transition, we propose a simple model for a classical 2-D electron system consisting of interacting electrons with random disorder and temperature. We monitor the fluctuations and noise characteristics of the current as a function of electron density or temperature. The advantage of our model is that a large number of interacting electrons can be conveniently simulated, while a full quantum mechanical model of similar size would be computationally prohibitive. Despite the limitations of this model, we find that this approach captures many of the key experimental observations [1].

In the left panel of Fig. 1, we show the velocity response of our simulated sample for fixed disorder and different electron densities as the temperature is decreased toward zero. At high electron density (top curve), the sample remains conducting down to zero temperature, as illustrated by the nonzero intercept of the curve. This is a metallic-like behavior. As the electron density is decreased, we find a transition to a regime where the velocity drops to zero within our resolution at a finite temperature. This behavior is consistent with an insulating state.

We next perform a series of simulations in which we measure the relative velocity fluctuations as a function of time for different points on the temperature-electron density phase diagram. When the system is in the metallic regime, as shown by the top curve in the right panel of Fig. 1, the magnitude of the velocity fluctuations is small. In contrast, as the electron density is decreased toward the metal-insulator transition, the size of the relative velocity fluctuations increases by several orders of magnitude (bottom curve). This dramatic behavior is in good agreement with the recent experimental measurements. We find that the velocity noise power appears to diverge both as the electron density is lowered and as the temperature is lowered. Single electron models would predict a *decrease* in velocity noise with decreasing

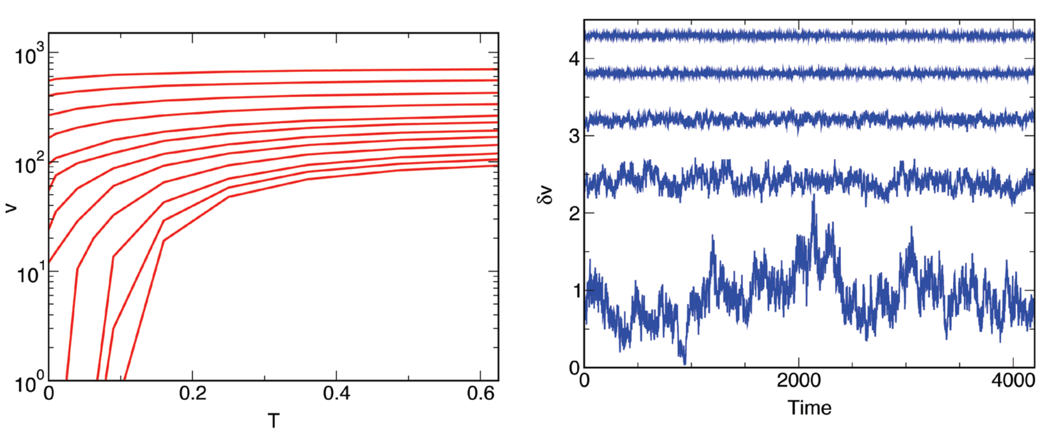

Fig. 1.
Left: The average electron velocity v versus temperature for increasing electron density, from bottom to top. Right: The relative velocity fluctuations δv versus time at fixed temperature for increasing electron density, from bottom to top.

temperature, in contrast to both the experiments and to our simulations, where electron-electron interactions are important.

We find that the large noise just above the insulating transition is due to correlated regions of stringlike electron flow, and that within these regions the electrons move in 1-D or quasi-1-D channels. Because of the reduced dimensionality, the electron motion is more correlated. In Fig. 2 we show the trajectories of the electrons for a fixed period of time for systems held at the same temperature but with a decreasing density of electrons. In Fig. 2(a), the system is in the metallic-like state, and the electrons can flow freely throughout the sample. In Fig. 2(b), larger pinned regions appear and the electron motion consists of a mixture of 2-D and 1-D regions. In Fig. 2(c), where the noise power is at its maximum just above the insulating transition, the electron motion occurs mostly in the form of 1-D channels that percolate through the sample. The channel structures change very slowly with time, with a channel occasionally shutting off while another emerges elsewhere. It is the intermittent opening of the 1-D channels which gives rise to the large noise fluctuations in this regime. When a percolating 1-D channel opens, all the electrons in that channel move in a correlated fashion leading to a large increase in the conduction. Conversely, if a percolating channel closes, all the electrons in that channel cease to move. Our simple model for the glassy freezing of interacting electrons in 2-D with random disorder agrees well with experimental measurements of the 2-D metal-insulator transition, and suggests that correlated electron motion plays an important role in the transition region.

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[1] C. Reichhardt and C.J. Olson Reichhardt, *Phys. Rev. Lett.* **93**, 176405 (2004).

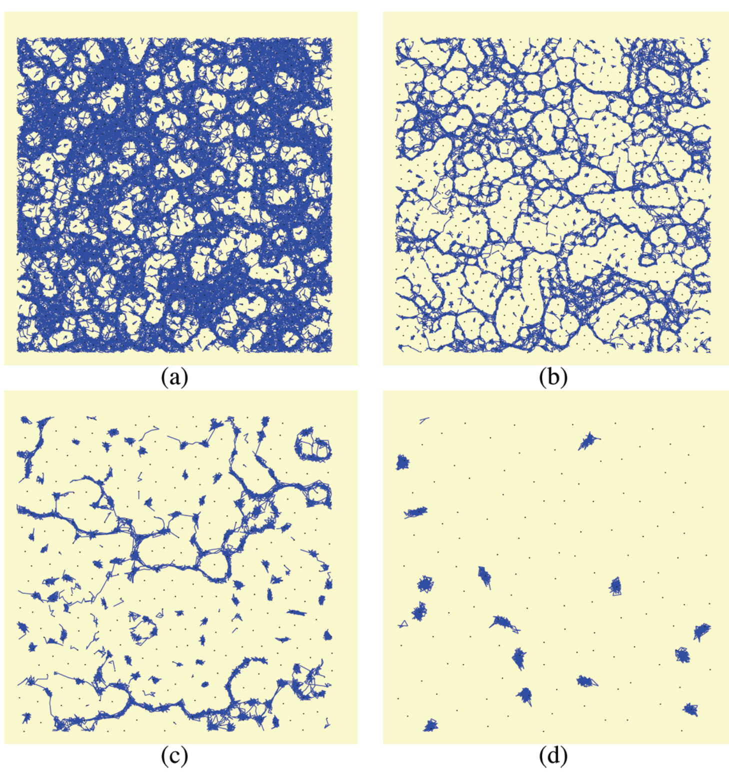

Fig. 2.
Classical electron trajectories for a fixed period of time for fixed temperature and decreasing electron density. (a) An electron liquid in the metallic-like regime. (b) Inhomogeneous electron flow at lower densities. (c) Filamentary, effectively 1-D electron flow at densities just above the insulating transition. (d) The insulating state where no electron transport occurs.